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Effects of Current Transformers Saturation on Coordination and Operation of Distance Relays, A Glance From New Angle

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Abstract— **In this paper the incorrect operation of distance relays and delay existence in its performance due to CT (Current Transformer) saturation is investigated. Also the effect of transform ratio of CT on distance relay operation is considered and sorted. As a case study the data of a practical transmission network (230 kV) have been used. The simulation has been done for various types of faults and the worst state of faults for distance relays inaccurate operation during CT saturation is introduced. The simulation has done with *PSCAD/EMTDC* software.**

Keywords- ***distance relay, fault, short circuit, saturation, transform ratio***

Introduction *(Heading 1)*

The main protection in transmission systems is distance protection. If the distance relays can't operate correctly the system will be vulnerable and this enforces uncompensable damages to power systems. The saturation of CT in fault occurrence condition is one of the factors which cause inaccurate performance of distance relays.

Current transformers adjust to work in point that they don't saturate even for currents more than ten times nominal current. However in transmission lines because of voltage higher level the current value is low. So the used CTs have low transform ratio. Also in these lines because of their proximity to power plants, the SCC(short circuit capacity) value is high and the short circuit current can saturate CT. this phenomenon will lead to incorrect operation of protective system. There are many papers that consider to effects of CT saturation and its simulation. In these papers some methods such as imaginary impedance[1], using from current components[2], using from secondary waveforms distortion[3] have been introduced. In this paper the effects of CT saturation on operation of distance relay is discussed. It will be shown that time delay and inaccurate operation of distance relay because of CT saturation can be increased in so far as which the time misscoordination of distance relays and unnecessary interruption in network may be occurred. Also the effects of CT transform ratio and various short circuit faults on distance relay performance will be investigated.

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I. EQUIVALENT CIRCUIT OF CT IN SATURATED STATE

Various methods have been introduced for simulation of saturated transformers. The figure 1 shows the simplified equivalent circuit of CT in normal condition [4-9]. In this circuit:

R_b and R_2 burden resistance and CTs secondary resistance

L_b, L2 and L_m burden inductance, secondary leakage inductance and magnetizing inductance

i_p and i_s primary and secondary currents. V is induced voltage in secondary

n the transform ratio of CT.

in normal condition the secondary voltage and created flow don't cause the saturation of CT. by increasing in primary current value, the secondary current will be increased as same ratio. This affair leads to increase in induced voltage in secondary and the raise of magnetizing current and consequently the CT goes to saturation state. In other words magnetizing inductance is decreased and the magnetizing branch will absorb almost the secondary current and any current can't arrive to load relay. [4, 8, 9] The equivalent circuit of this state has been shown in figure2.

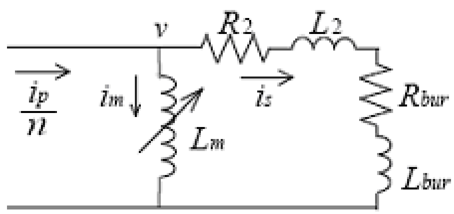

Figure 1: equivalent circuit of CT

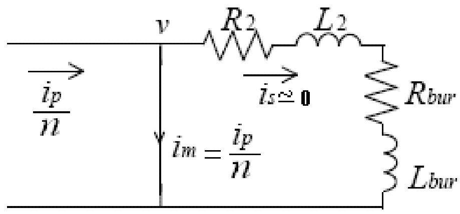

Figure 2: the equivalent circuit of saturated CT

In this state the output current of CT has distortion and as a result distance relay will slip in measouring of fault impedance and operation. For instance the sample of current saturation of CT has been shown in figure3.

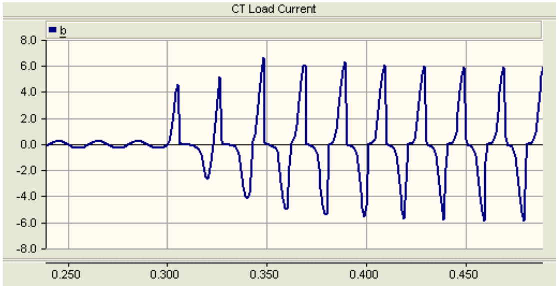

Figure 3: the waveform of saturated CT

This figure shows the output current of sample CT which the short circuit has occurred in primary side of CT in t=0.3 second. The short circuit current has been raised to 20 time of nominal current.

II. TRANSFORM RATIO EFFECT ON CT SATURATION

The figure 4 shows the excitation curve of two similar CT with different transform ratio. As seen in figure 4 , in a distinct excitation current with decreasing of transform ratio the excitation voltage decrease also and consequently the output current is reduced.

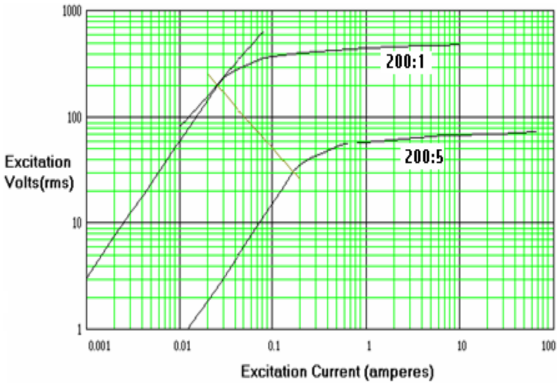

Figure 4: the excitation of two similar CT with different transform ratio

If the both similar CTs are saturated with transform ratio of 2000/1 and 2000/5, the saturation of CT with ratio of 2000/5 is more intense. This concept has been illustrated in figure 5 which one short circuit fault has been occurred in primary side of CT in t=0.3 second and the current of CT has been grown to 20 time of nominal current.

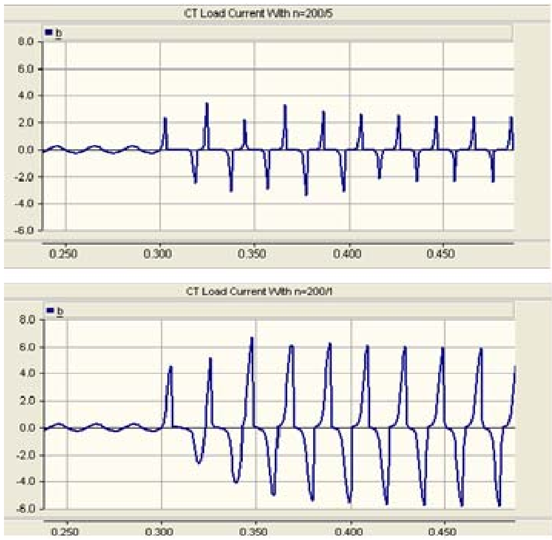

Figure 5: load current of two similar CT with transform ratio of 200/1 and 200/5

III. CASE STUDY

The simulated network is shown in figure 6. This is a transmission line with length of 300 km and voltage level of 230Kv. The voltage source has been considered as tevenin equivalent circuit of of 230 kV network with short circuit capacity (SCC) of 6000 MVA. The load in the end of line has been considered with power factor of 0.85 lag. The details of transmission line have been shown in tables I and II.

TABLE I. THE DETAIL OF TRANSMISSION LINE

Conductor type	chukar
Conductor	Horizontal line
Number of bundels	2
Distance of conductors in bundles(cm)	30
Conductor diameter(cm)	2
Conductor dc resistance(ohms/km)	0.081
Line inductive impedance(ohms/km)	0.304
Distance of phases (m)	8
Conductors distance from earth(m)	25
Distance of guard cords(m)	8
Distance of guard cords from earth(m)	31
Average distance of line bulge(m)	5
Line length(km)	300

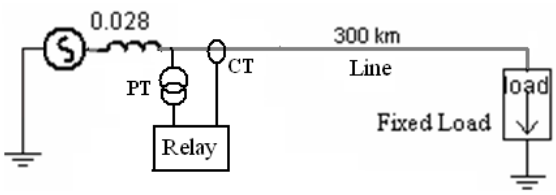

Figure 6: simulated transmission system

Table II: PARAMETERS OF THE EARTH

Earth resistance (ohm/km)	200
Earth relative u	1

The used distance relay in simulation is from kind of 60 degree mho relay. The used model for CT is as reference [4]. The characters of CT are shown in table III.

Table III: THE CHARACTERS OF USED CT IN SIMULATIONS

Number of primary turns	**First CT**	1
	Second CT	5
Number of secondary side		200
Secondary resistance (ohm)		0.5
Secondary inductance (H)		0.0008
Average length of core(m)		0.6377
Area of core (m^2)		0.026

IV. CT SATURATION EFFECT ON DISTANCE RELAY IN FIRST ZOON

For investigation on CT saturation effect, the input current has been supplied by ideal ampere mete first and by CT again. The figures 7, 8, 9 and 10 show the seen impedance variation curves by distance relay. In these figures respectively the phase to ground (L-G), phase to phase(L-L), two phase to ground(L-L-G) and three phase (L-L-L)faults in three protectional zones has been applied. These faults applied at t=0.3 second. The transform ratio has been chosen 200/1 first and 200/5 again. In all of the figures the left figure is related to transform ratio 200/1 and the right figure is related to transform ratio 200/5.

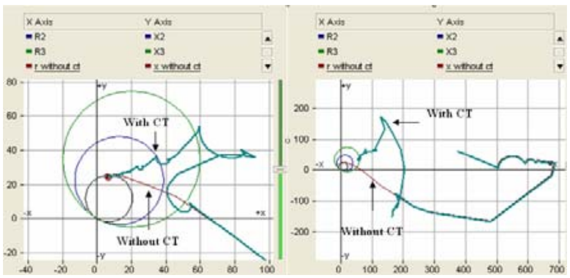

Figure 7: the curve of seen impedance variation in phase to ground fault in first zoon

As seen in left figure in 7, with saturation of CT and occurrence of fault in latest section of first zoon the distance relay can detect the fault. While wit changing the transform ratio from 200/1 to 200/5 the occurred fault in first zoon is detected as third zoon fault. Additional to incorrect detection the delay of operation is at least 0.8 second. This concept has been illustrated in right figure.

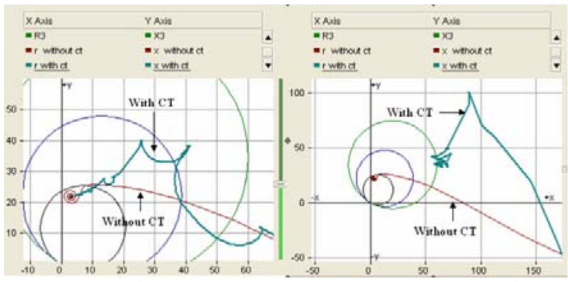

Figure 8: the curve of seen impedance variation in phase to phase fault in first zoon

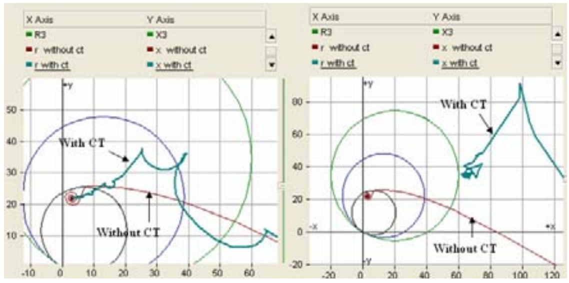

Figure 9: the curve of seen impedance variation in two phases to ground fault in first zoon

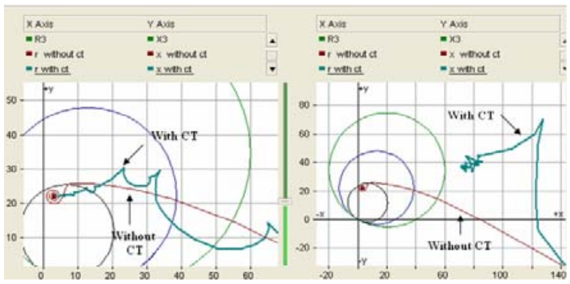

Figure 10: the curve of seen impedance variation in three phase fault in first zoon

The results of relay operation have been summarized in table IV. The important point is that the relay can not to detect the two phase to ground and three phase faults in 200/5 transform ratio state.

Table IV: THE OPERATION OF RELAY N FAULT OCCURRENCE IN FIRST ZOON IN CT SATURATION CONDITION

Fault type	**Fault zoon**	**Detected zoon for occurred fault in 200/1 TR**	**Detected zoon for occurred fault in 200/5 TR**
L-G	1	1	3
L-L	1	1	3
L-L-G	1	1	Not detected
L-L-L	1	1	Not detected

V. CT SATURATION EFFECT ON DISTANCE RELAY IN SECOND ZOON

The achieved results for distance relay operation when the faults occure in second zoon have been shown in figures 11 to 14.

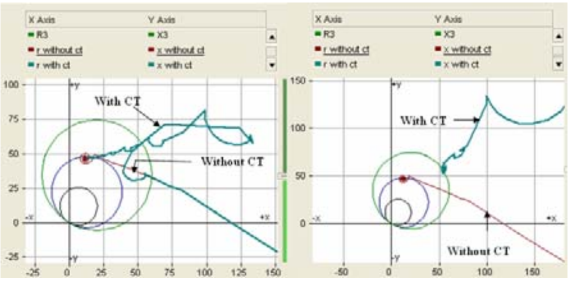

Figure 11: the curve of seen impedance variation in phase to ground fault in second zoon

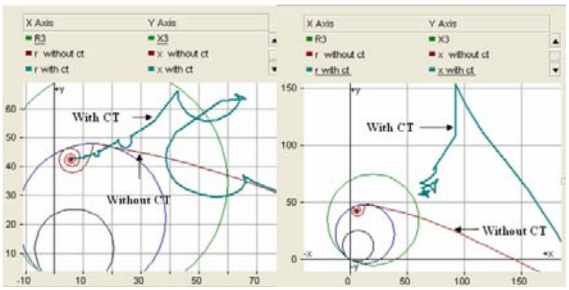

Figure 12: the curve of seen impedance variation in phase to phase fault in second zoon

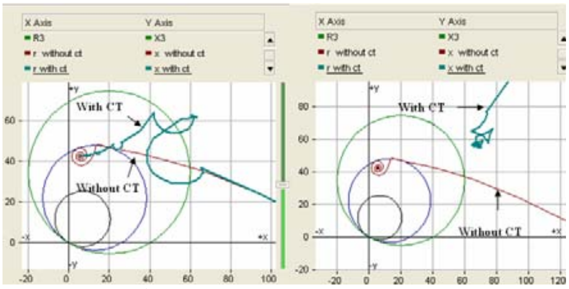

Figure 13: the curve of seen impedance variation in two phases to ground fault in second zoon

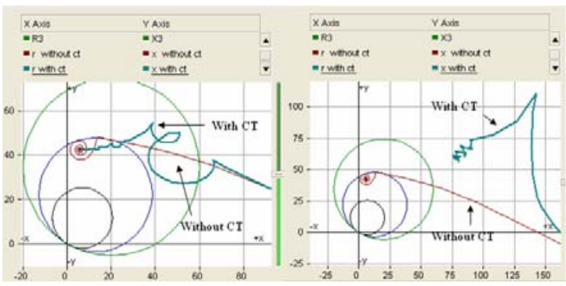

Figure14: the curve of seen impedance variation in three phase fault in second zoon

The results of relay operation in fault occurrence in second zoon have been summarized in table 5.

Table V: THE OPERATION OF RELAY N FAULT OCCURRENCE IN SECOND ZOON IN CT SATURATION CONDITION

Fault type	**Fault zoon**	**Detected zoon for occurred fault in 200/1 TR**	**Detected zoon for occurred fault in 200/5 TR**
L-G	2	2	3
L-L	2	2	Not detected
L-L-G	2	2	Not detected
L-L-L	2	2	Not detected

VI. CT SATURATION EFFECT ON DISTANCE RELAY IN THIRD ZOON

The achieved results for this state that faults occur in third zoon have been shown in figures 15 to 18.

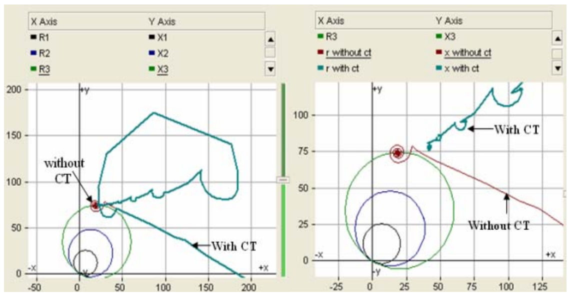

Figure 15: the curve of seen impedance variation in phase to ground fault in third zoon

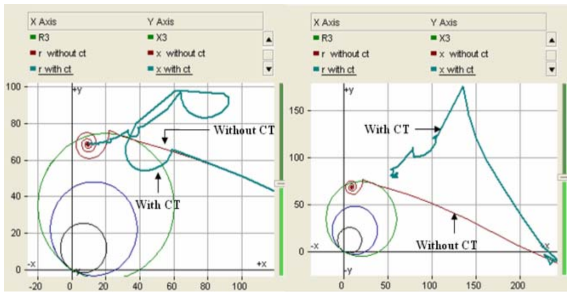

Figure 16: the curve of seen impedance variation in phase to phase fault in third zoon

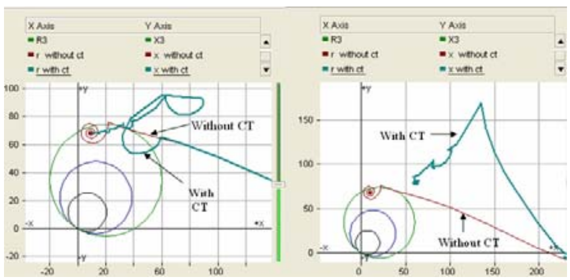

Figure 17: the curve of seen impedance variation in two phases to ground fault in third zoon

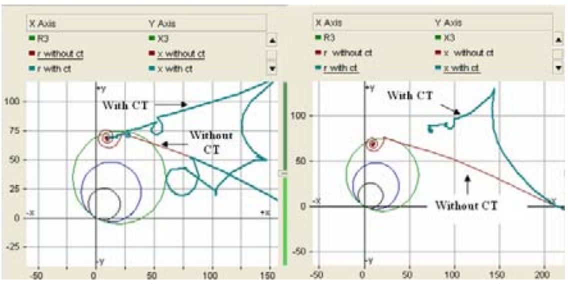

Figure18: the curve of seen impedance variation in three phase fault in third zoon

If the results of the above figures have been summarized in a table the table VI will achieved.

Table VI: THE OPERATION OF RELAY N FAULT OCCURRENCE IN THIRD ZOON IN CT SATURATION CONDITION

Fault type	**Fault zoon**	**Detected zoon for occurred fault in 200/1 TR**	**Detected zoon for occurred fault in 200/5 TR**
L-G	3	3	Not detected
L-L	3	3	Not detected
L-L-G	3	3	Not detected
L-L-L	3	3	Not detected

VII. DELAY IN OPERATION OF DISTANCE RELAY

When the CT transform ratio is 200/1, the CT can detect the fault correctly. However it is clear that the seen impedance curve have many tolerances till steady state compare to ideal condition. Also it is seen that the impedance variation curve enter to related protected zoon by much delay compare to ideal condition and arrive to fault point. For example this process can be seen in phase to ground fault condition in first zoon which has been shown in figure 7. In this state relay operation done with delay. The figure 19 shows this concept.

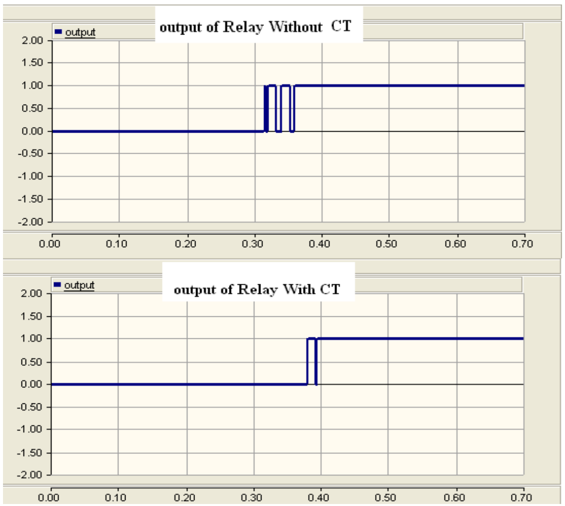

Figure 19: relay output in phase to ground fault in first zoon in 200/1 TR (Transform Ratio)

With a glance to figure 19 it is understood that the fault have been occurred in t=0.3sec and in ideal condition relay has tripped in t=0.32 sec. but in present of CT the relay has delay about 0.06 sec and has tripped in t=0.38sec. If the CT transform ratio changed from 200/1 to 200/5, the miss operation of CT will be intense. Although the fault is in the protected section but it is seen that the impedance variation curve is not entered to mentioned zoon and consequently relay don't trip and fault is not detected.

The figure 20 show the output of distance relay in two state of feed by ampere meter and feed by CT in phase to ground fault which occur in t=0.3 sec and inside of first zoon. As know in this mood the relay should trip but because of transformer saturation relay make mistake and don't trip.

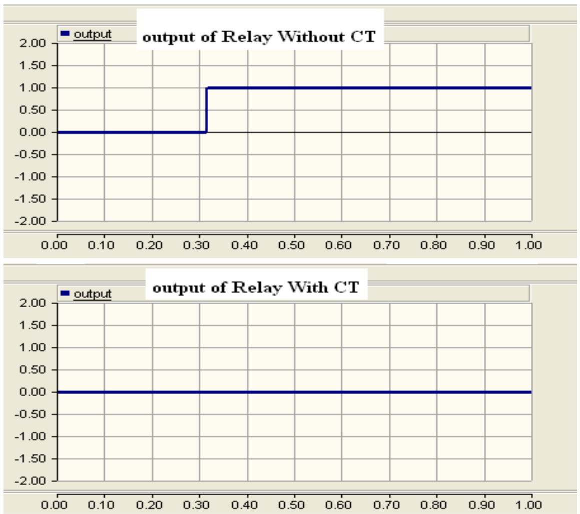

Figure 20: relay output in phase to ground fault in first zoon in 200/5 TR (Transform Ratio)

VIII. CONCLUSION

In this paper the effects of CT saturation on behavior of distance relay during the various faults occurrence was investigated. The simulation results showed that saturation can be lead to incorrect detection of fault location (zoon) by distance relay. In some cases the relay couldn't detect the fault basically because of CT saturation. Also the effects of transform ratio on CT saturation and relay performance were probed. In cases that relay could detect the faults, its operation has delay and this can be lead to misscoordination of distance relays. According to results it was seen that if the fault location be closer to source then the operation of relay will be worse. The worst operation of relay occur in three phase short-circuits. The two phases to ground, two phases and one phase to ground are in next steps in this ranking.

BIOGRAPHY

Hadi Hosseinian was born in Hashtrood, Iran, in 1983. He received the B.Sc. degree in electrical engineering from Tabriz University, Iran, in 2005 and the M.SC degree from Zanjan University in Iran in 2008. His research interests include power system protections, power quality and application of artificial intelligent in power systems.

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